Report for 2005NJ84B: The Influence of Urbanization on Watershed Nitrogen Cycling Watersheds

Publications

- Other Publications:
  - Rosenzweig, B. and P. Jaffe. December, 2005. Stormwater Detention Ponds and Nitrogen Cycling in Urban Watersheds. In Poster Presentation at the American Geophysical Union Fall Meeting.
  - Rosenzweig, B. and P. Jaffe. May, 2006. The Significance of High Discharge Events to Nitrogen Transport in Urban Watersheds. In Poster Presentation at the AGU Joint Assembly Meeting.

Report Follows

Problems

As the amount of land devoted to urban and suburban use increases, understanding the impact of this type of development on ecosystem processes will become increasingly important. This issue is one of particular urgency in the state of New Jersey, where 27% of the total land area was categorized as urban at the end of the 20th century and approximately 16,600 acres of land are converted to urban development each year (Hasse and Lathrop, 2001). In spite of its importance, the study of nutrient cycling in urban watersheds is still in its infancy. Our research investigates the coupled hydrologic and nitrogen cycles in an urban watershed and how they are modified by urban land use.

Understanding the dynamics of nitrogen is particularly important because, when transported in excess to coastal ecosystems, this nutrient can lead to harmful coastal eutrophication. Well-publicized examples of this phenomenon include the 'dead zone' in the Gulf of Mexico and the anoxia problem in the Chesapeake Bay (Mitsch et al. 2001). Previous research (Groffman et. al., 2002) has shown that riparian zones can serve as important control points in determining the amount of nitrogen that will enter surface waters and eventually be transported to coastal systems. The hydrologic changes induced by urbanization can significantly modify the ability of riparian systems to process nitrogen.

We would like to determine how hydrologic changes resulting from urban land use influence the occurrence of these locations and periods of biogeochemical importance (McClain, 2000). Our work tests the following hypotheses:

- Urban land development leads to modifications in the mechanisms of runoff production and modifications to stream channel morphology
- As a result of these physical and hydrologic changes, urban stream channels have reduced capacity for nitrogen retention and can no longer function as watershed-scale hotspots of nitrogen removal and retention. Urban development also creates additional sources of nitrogen that can be transported by streams.
- As a result of these physical and hydrologic changes, there are enhanced cycles of subsurface wetting and drying which can result in 'hot moments of nitrogen export from urban watersheds
- Stormwater detention ponds function as hot spots of nitrogen retention in urban watersheds

Methodology

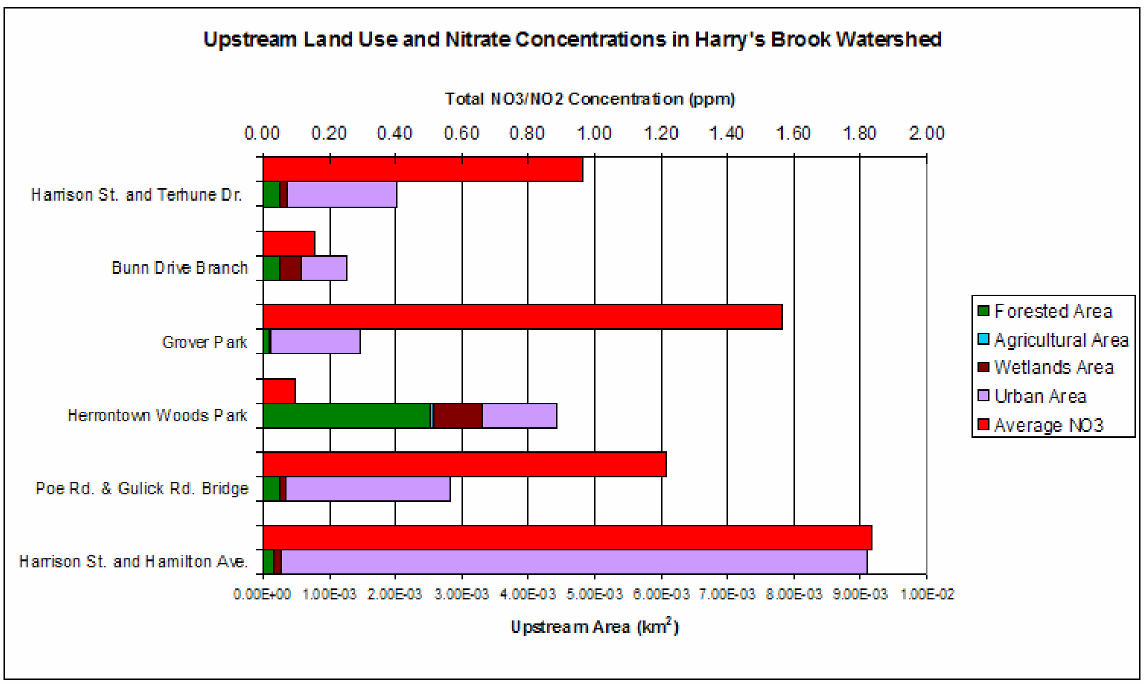
Our research to date has focused on characterizing spatial and temporal variation in stream nitrogen loads in the Harry's Brook watershed in Princeton, NJ. This 6.7 km^2 watershed contains a great deal of diversity in its development history. It consists of a branch that remains undeveloped as a forest preserve, branches of pre-Clean Water Act development where no structural best management practices (eg. detention ponds) are in place and branches where detention ponds are used for stormwater control.

In order to investigate spatial and seasonal variation in instream nitrate concentrations, grab samples were collected regularly during low flow conditions at 26 sampling sites throughout the watershed. Stream gages were located at 6 of these sites and record a continuous time series of stage at 1-minute intervals. The stream nitrogen response to storm events was also assessed by obtaining time series of water quality samples during storm events. Storm event samples were collecting using ISCO 6712 Automated Samplers at intervals from 15 minutes to 1 hour. The storm event results provided in this report were obtained at the Terhune Rd. site, where a rating curve has been developed to relate stream stage to discharge.

Water quality samples were filtered using 0.2µm nylon filters and analyzed for Total NO_3^-+NO_2^- , NH_3, and Total Dissolved Nitrogen using a Lachat Quik-Chem 8500 Flow Injection Analyzer. Samples were also analyzed (without filtration) for TOC using a Shimadzu TOC-500 Combustion Analyzer. For this study, we were most interested in NO_3, which is usually present in dissolved form and easily transported to surface waters. (NO_2^- in Harry's Brook surface waters can be assumed to be negligible. Future work will also focus more on other forms of nitrogen, in which a significant fraction is sorbed to particles as well as in dissolved form. The procedures developed for storm event sampling and analysis will be modified for future use in University campus detention ponds this summer.

Principal Findings and Significance

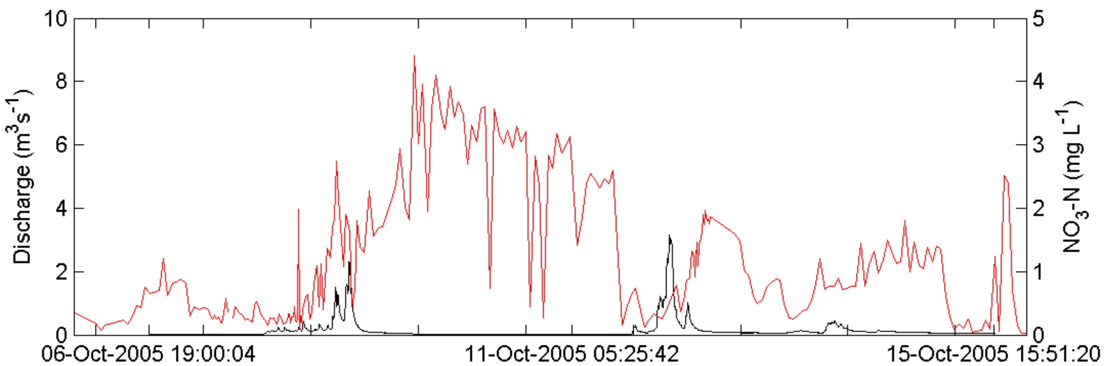
Our results from this work show that there is significant spatial variation in instream nitrogen loads and that this variation can be correlated to land use. The figures below summarize results from 6 representative sites throughout the watershed with varying upstream catchment area and land use. Upstream Land Use was assessed using the New Jersey Department of Environmental Protection's 1995-1997 Land Use/Land Cover Dataset and 10m Digital Elevation Models.

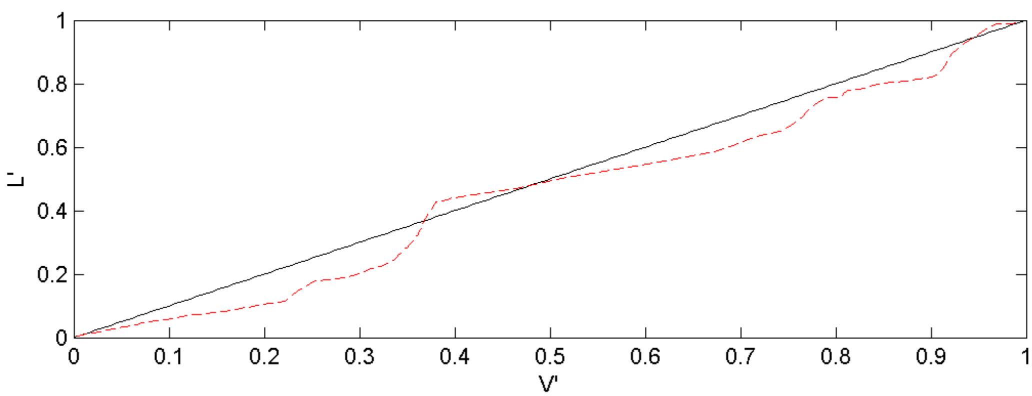


The total NO_3 concentrations shown in the chart above are the average from 12 sampling events. Sites with highly urbanized upstream catchments, such as the Grover Park site that drains the commercial area of the Princeton Shopping Center and the Hamilton Ave site downstream of the downtown Princeton storm drain outfall, tend to have higher instream NO_3 concentrations than less developed sites such as the Herrontown Woods Forest Preserve site. Upstream Land Use seems to be a more important control on instream nitrate concentrations than catchment area- for example the Grover Park site is much smaller in area than the Hamilton Ave Site, but both have comparably high average NO_3^- concentrations.

Our most significant storm event sampling took place during a 9-day period in October, 2005 in which the Harry's Brook Watershed received ~300 mm of rainfall. This was an extreme rainfall event in this region- the average rainfall for the entire month of October in the Princeton area is only 86mm. In spite of the significant rainfall, this was not a high discharge even since it followed an extremely dry summer. The rainfall was distributed with two periods of peak intensity on October 8th and 12th (with 166 and 77 mm of rainfall reported, respectively) with intermittent periods of light rain in between.

The figure below shows time series of discharge and NO3- as well as a dimensionless L'V' Curve:





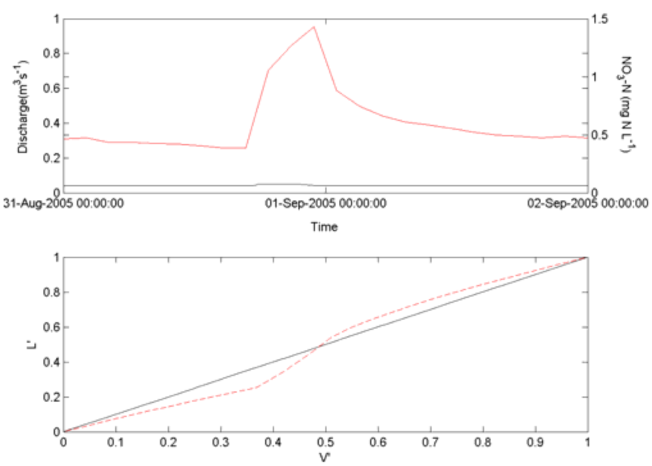
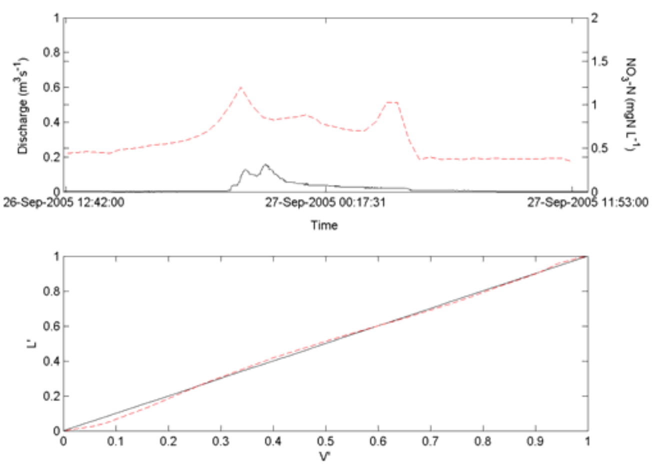
Average baseflow in 24 hours preceding event:	n/a*
Total Baseflow in 24 hours preceding event:	n/a*
Days since previous rainfall event (>0.1cm of rain):	8 days
Event Total Flow Volume (24 hours):	105067 m^3
Event Total NO_3 Load:	60 kg
Event Avg. Conc:	1.2 ppm

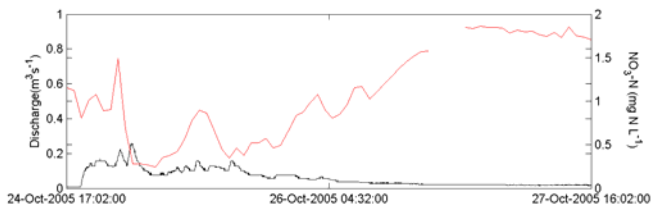
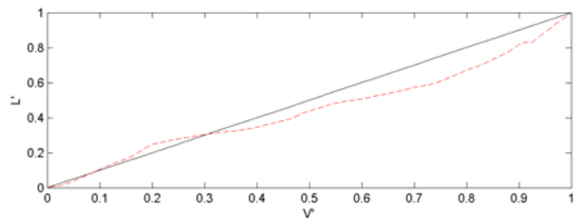
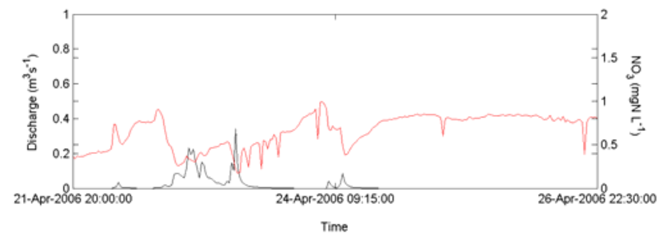
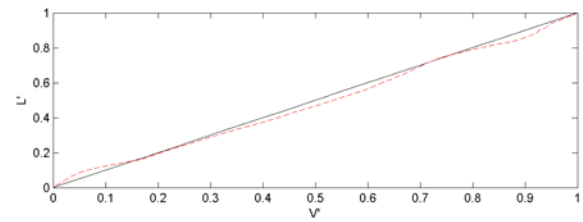
*The stream gage at this site was offline until the morning of 10/6/2006

L'V' curves compare the timing of the total analyte load that has been transported to the site (normalized cumulative load, L') to the fraction of the total runoff volume (normalized cumulative discharge, V') that has passed through the site from their source within the watershed. The 'first flush' phenomena (Deletic, 1998) commonly described in the literature would appear when >75% of the total analyte load has passed through the site when only 25% of the runoff volume has.

We did not observe a first flush for nitrate during this event. Instead, the nitrate response lags behind the runoff hydrograph until the receding limb of the first discharge peak. This may indicate that the analyte is being transported by slower pathways (e.g. shallow subsurface flow), while the bulk of the stormwater runoff takes more rapid routes (eg. rapid runoff over impervious surface and through storm drain networks). Extremely high nitrate concentrations (with a maximum of 4.5ppm, which is greater than that observed in all of our sampling efforts at Harry's Brook) were observed approximately 12 hours after the most intense period of rainfall. These data suggest that the period during the receding limb of an extreme storm hydrograph may constitute a hot moment of nitrogen export. This is significant since many stormwater BMPs are now being designed to capture the first flush of stormwater for water quality improvement and would, as a result, not reduce the bulk of the nitrate load being exported at this site. Further work is necessary to determine the significance of this event to annual nitrogen loads in Harry's Brook.

For comparison, the results from four more typical storm events evens are shown below. These figures show time series of discharge (black line) and NO_3 concentration (red line) and the corresponding L'V' curves at the Terhune Rd. site.

August 31st, 2005 Event	**September 26th, 2005**
	
Rainfall: 6.1mm in 2 hrs Days since previous rainfall event (>0.1cm of rain): 16 days Average Baseflow in 24 hours preceding event: extremely low Event Total Runoff Volume (24 hours): 3728.5m^3 Event Total NO3 Load: 2.1 kg Event Avg. NO3 Conc. 0.57ppm	Rainfall: 14.5 mm in 3 hrs Days since previous rainfall event (>0.1cm of rain): 11 days Average baseflow in 24 hours preceding event: 0.002cms Total Baseflow in 24 hours preceding event: 158.08m^3 Event Total Flow Volume (24 hours): 1834.9 m^3 Event Total NO3 Load: 1.4 kg Event Avg. Conc: 0.78ppm

October 24th, 2005 Event	April 22nd, 2006 Event
  	 
Rainfall: 48mm in 2 days Days since previous rainfall event (>0.1cm of rain): 2 days Average baseflow in 24 hours preceding event: .009cms Total Baseflow in 24 hours preceding event: 780.8m^3 Event Total Flow Volume (72 hours): 15879.21 m3 Event Total NO3 Load: 13 kg Event Avg. NO3 Conc. 1.1 ppm	Rainfall: 62.4mm in 2 days Days since previous rainfall event (>0.1cm of rain): 7 days Average baseflow in 24 hours preceding event: extremely low Event Total Flow Volume (124 hours): 6516 m3 Event Total NO3 Load: 2.5 kg Event Avg. NO3 Conc. 0.66 ppm

Our results show that there is considerable variation in both the total NO_3-N load that will be exported with any given event and the timing of the nitrate response. The intensity and duration of precipitation, time of year and, most importantly, antecedent conditions appear to play a role in determining the nitrate response. For example, the October 24th, 2005 and April 22nd, 2006 storms were comparable in magnitude and duration but produced very different N loads at this site. This was probably resulted from high instream N concentrations before the October 24th storm as a result of the extreme event a few weeks earlier.

Further work is required to better understand the controls on nitrogen transport to streams by stormwater. The results will be used to better understand the potential large-scale role of detention ponds in watershed nitrogen cycling. Future work will also be conducted within detention ponds to determine whether they are sources or sinks of nitrogen and the key N cycling processes within them. Our ultimate goal is to optimize the design of stormwater detention ponds to act as ‘sinks’ of nitrogen in urban watersheds.

Cited References:

Deletic, 1998. The First Flush Load of Urban Surface Runoff. Water Resources. 32. p. 2462-2470.

Groffman, P.M., N.J. Boulware, W.C. Zipperer, R.V. Pouyat, L.E. Band, and M.F. Colosimo. 2002. Soil nitrogen cycling processes in urban riparian zones. Environmental Science and Technology **36**:4547-4552.

Hasse, John and Lathrop, Richard, 2001. Measuring Urban Growth in New Jersey. Center for Remote Sensing and Spatial Analysis Report. Rutgers University, New Brunswick, NJ.

McClain, M.E., E.W. Boyer, C.L. Dent, S.E. Gergel, N.B. Grimm, P.M. Groffman, S.C. Hart, J.W. Harvey, C.A. Johnston, E. Mayorga, W.H. McDowell, and G. Pinay. 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. Ecosystems **6**:301-312.

Mitsch, W.J., J.W. Day, Jr., J.W. Gilliam, P.M. Groffman, D.L. Hey, G.W. Randall and N. Wang. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River basin: Strategies to counter a persistent ecological problem. BioScience 51:373-388